A SOLID STATE SURGICAL MONITOR FOR VETERINARY MEDICINE

by

Michael Dinsmore Stout

United States Naval Postgraduate School

THESIS

A SOLID STATE SURGICAL MONITOR
FOR VETERINARY MEDICINE

by

Michael Dinsmore Stout

December 1970

This document has been approved for public release and sale; its distribution is unlimited.

A Solid State Surgical Monitor
For Veterinary Medicine

by

Michael Dinsmore Stout
Lieutenant, United States Navy
B.S., United States Naval Academy, 1963

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December 1970

ABSTRACT

A concept for an apparatus which provides audio and visual monitoring of the heart function is developed, including circuitry to give indications of abnormal conditions. The machine is intended for use during surgery by doctors of veterinary medicine, but also may have some application for monitoring of human patients. System design and principles applied to realize a physical prototype of this concept are presented. The complete electronic and mechanical design plus fabrication of the surgical monitor is described in detail. Schematic diagrams of all electronic circuitry employed and photographs of the prototype equipment are included, along with a set of operating instructions for non-technically trained personnel. The device is on loan to the Monterey Bay Pet Hospital, Monterey, California, for further field testing and evaluation.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SYMBOLS AND ABBREVIATIONS

D.V.M.	Doctor of Veterinary Medicine
EKG	Electro-cardiogram
FET	Field Effect Transistor
N	Intrinsic Standoff Ratio
PR	Pulse Rate
PS	Pulse Strength
SCR	Silicon Controlled Rectifier
SCS	Silicon Controlled Switch
UJT	Unijunction Transistor
V_{BB}	Interbase Voltage, Base One to Base Two
V_D	Emitter Diode Voltage Drop
V_{in}	Input Voltage
V_p	Peak Voltage

ACKNOWLEDGEMENTS

The author is deeply indebted to Dr. Gerald D. Ewing of the Naval Postgraduate School Faculty for arousing interest in the subject of electronic instrumentation for veterinary medicine through the 1969 edition of the IEEE Student Branch Thesis Topics publication, and for his continuing interest and encouragement through the development of the prototype machine.

The author also expresses his appreciation to Dr. Dale C. Johnson of the Monterey Bay Pet Hospital for his valuable assistance and time in defining priority problems in veterinary medicine and for his invaluable assistance in clinical testing of the breadborad and prototype models of the VETSMON device.

I. INTRODUCTION

A. THE PROBLEM

In recent years, the field of Bio-Medical Engineering has become increasingly more important. The electronics industry and its design engineers have devoted continuing effort to developing and producing specialized electronic equipment to aid the general practitioner of human medicine in diagnosis, and to aid the surgeon in the operating room. Much of this equipment has become basic to the practice of modern medicine, and doctors and surgeons rely heavily upon it.

Unfortunately, doctors of veterinary medicine have not benefited from this technological advance. To date, literally all of the bio-medical electronic equipment produced for commercial consumption has been designed for use in the practice of human medicine. Some of this equipment is useable, either directly or with some modifications, in veterinary medicine, but it has the singular drawback of being very expensive. Because of this high cost factor, monitoring systems for use during surgery are found almost exclusively in large hospitals and clinics for humans. Most veterinarians operate alone or in partnership with one other doctor, and they simply cannot afford this kind of equipment. As a consequence, they have absolutely no electronic aids in the practice of their profession, and must resort to such crude practices as having an assistant hold a stethoscope on the animal subject during surgery to keep them informed of whether

or not the "patient" is even alive. The condition of the animal in regard to shock, cardiac arrythmia, strength of the heart, etcetera, must be guessed at by the assistant, who is not usually well trained in this field.

B. THE SOLUTION

This thesis is directed towards providing a first step in filling the technological gap for practitioners of veterinary medicine by designing and building a prototype of a surgical monitoring instrument for use in veterinary medicine. The objective is to keep the price of the instrument small through the use of solid state technology and simplified input/output devices, while still providing a device which will give the operator sufficient information to continuously monitor the animals overall condition.

The device must be relatively compact, simple to operate, and if possible, be capable of being powered by an auxiliary battery pack for use by "large animal" D.V.M.'s in the field. Its output must be simple enough to be interpreted by a person with no electronics training, and yet, complete enough to be useful. The device must meet these requirements and still be producible commercially at a cost of 500 dollars or less.

Polls conducted among D.V.M.'s within the three surrounding counties aided in the identification of the output parameters most desired, and the input considered most reliable and easiest to obtain. Figure 1 is a block diagram of a generalized veterinary surgical monitor, henceforth referred to as the VETSMON, showing the input to be used and the outputs desired.

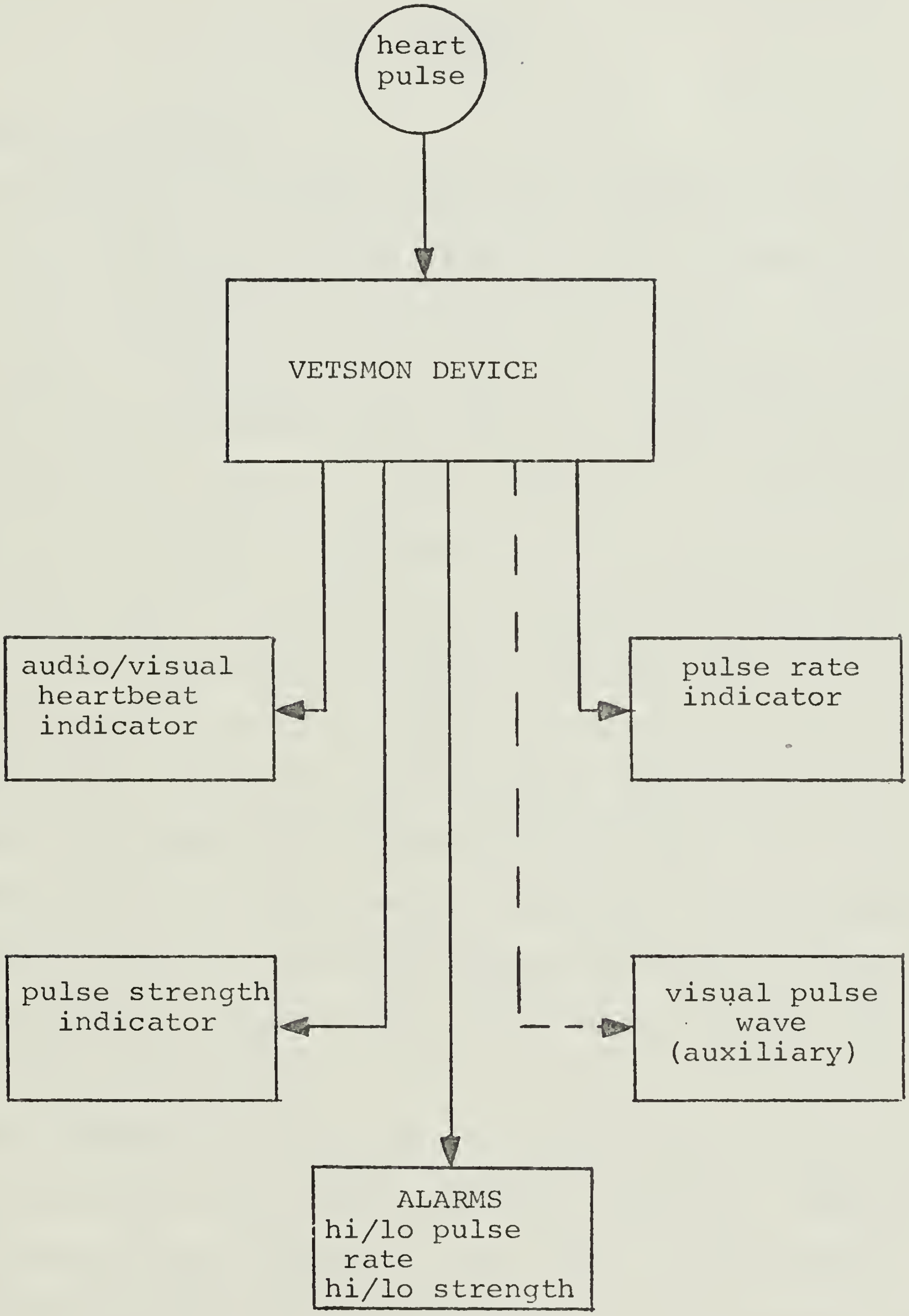

Figure 1. Veterinary Surgical Monitor (concept).

II. DESIGN

A. THE INPUT DEVICE

The choice of the input device was dictated by suitability, availability, and cost. Five types of input devices were considered: electro-cardiogram type skin probes, a fluid flow blood pressure transducer, an esophagial stethoscope (inserted down the esophagus so that the pickup is close to the heart), an electronically amplified stethoscope, and a piezo-electric crystal pressure pulse transducer.

The EKG type skin probes were eliminated because they require careful placement, would be very difficult to properly place on the skin of a fur covered animal, and because the pressure pulse wave gives a much quicker indication of cardiac arrythmia and change in the heartbeat strength.

The fluid flow blood pressure transducer was considered unsuitable because it requires venous insertion to obtain blood through it, and its cost is prohibitive (about 400 dollars for most units).

The esophagial stethoscope was simply not available, and since it was quite new, was relatively expensive. However, future research may warrant a closer look at this device, since it showed the possibility of providing a strong signal, and would probably be the easiest device to "attach" to an animal.

The electronically amplified stethoscope was eliminated because experimentation with a commercial model showed that

it naturally picked up any other sounds available, in addition to the heartbeat, causing spurious input signals which could have led to false output information.

The piezo-electric crystal pressure pulse transducer was finally settled upon as being the most satisfactory input device available. It can be placed on the body anywhere that a peripheral pulse can normally be detected, and when properly and firmly placed, it is insensitive to interfering signals of an audio or electromagnetic nature. It provides an electrical signal directly proportional to the pulse pressure wave, and most commercial models are inexpensive. Due to its immediate availability, the particular model chosen was the Harvard Model 361 Pulse Transducer. This model is capable of an output signal up to one tenth volt and has a retail price of twenty dollars. Due to its high output impedance, the Model 361 requires a load impedance of one megohm or greater.

B. THE GAIN/FILTER STAGE

Some experimentation with the pulse transducer showed that the actual output voltage was in the range of only ten to fifty millivolts even when used on a human subject. This indicated that a gain stage would be necessary to bring the signal up to a level where it would be useful in detecting and indicating circuits. As the amplitude of the output signal from the transducer depended on how firmly the device was held in place each time, the gain had to be continuously variable to permit setting the pulse wave strength at some fixed reference point not dependent on the size of the animal or firmness with which

the transducer was held in place. It was felt that this procedure would eliminate the necessity for an output device with a capability of reading over a wide range.

Due to the requirement of the Model 361, and indeed, any piezo-electric transducer, the gain stage had to have an input impedance of one megohm or greater.

To accomodate the desired signal, the low end of the frequency response characteristic of the gain stage had to extend down to at least one hertz. However, since the signal level at the input was comparable with the undesirable 60 hertz signal produced by fluorescent lighting (found in most veterinary operating rooms), the gain also had to roll off well below 60 hertz. This would cause no problem with the desired signal, since even a pulse rate of 600 beats per minute would correspond to a frequency of only 10 hertz.

The requirement for a high input impedance suggested an FET preamplifier, and the relatively inexpensive JFET 2N3819 was chosen as having suitable characteristics.

The requirement for a large, variable and stable gain indicated the use of a linear operational amplifier with variable feedback, and the internally compensated RM741 was chosen for its high common mode voltage range and high gain.

The desired frequency response characteristic was obtained by R-C filtering between the pre-amplifier/impedance converter and variable gain sub-stages, and by an additional simple low pass R-C filter in the output of the latter sub-stage.

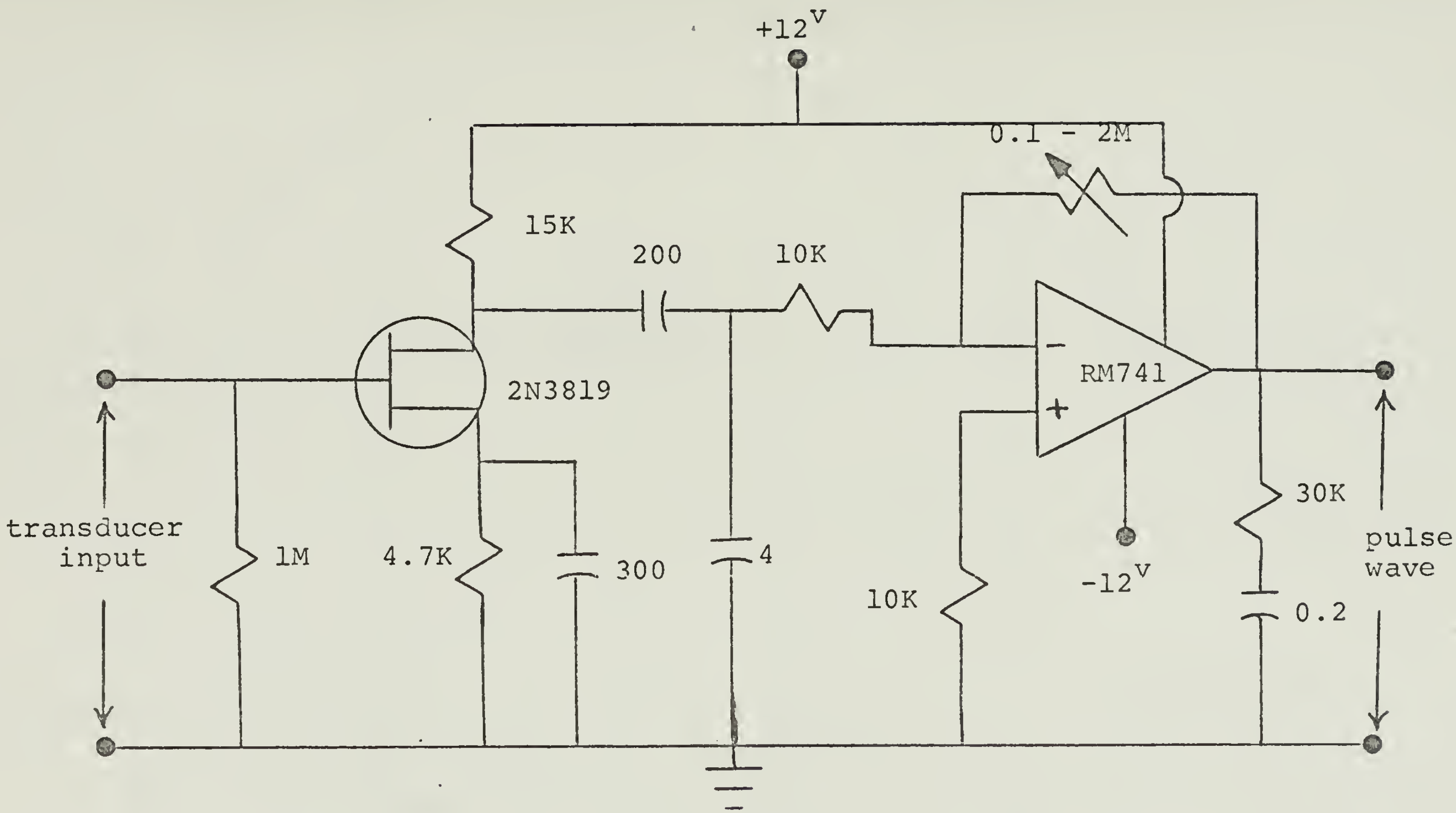

Figure 2. Gain/Filter Stage.

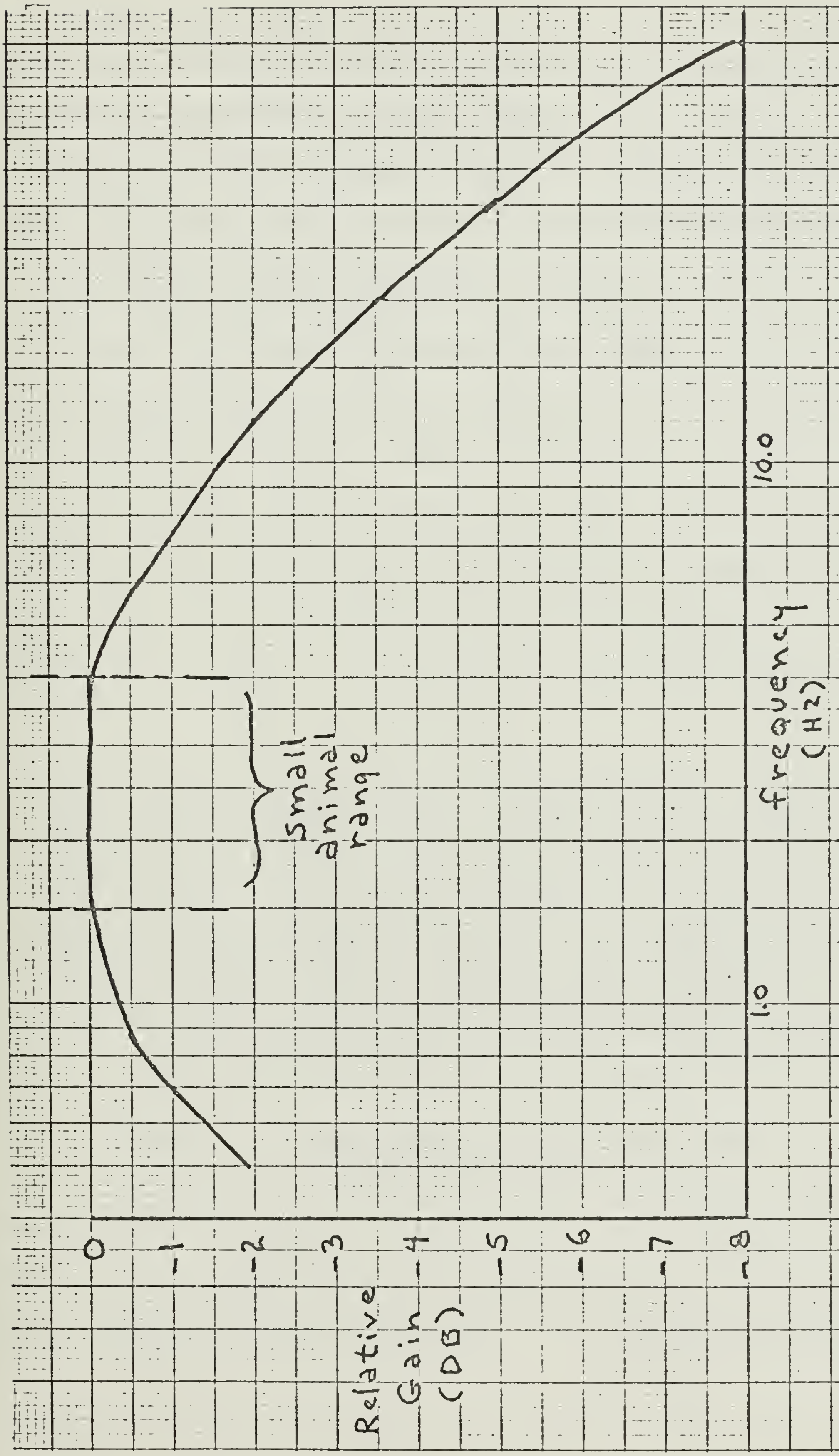

Figure 3- Gain/Filter Stage

Figure 2 is a schematic diagram of the Gain/Filter stage which resulted from the above design considerations. All schematic values shown in this thesis are in units of ohms or micro-farads unless otherwise noted. Figure 3 is a plot of the Gain/Filter stage frequency response characteristic.

C. THE PULSE STRENGTH INDICATOR CIRCUIT

Figure 4 is a reproduction of the output of the Gain/Filter stage obtained when the pulse transducer was attached to a human subject. This is a good representation of the type of signal that was expected from any animal, although it would naturally vary in amplitude and frequency. Since the Gain/Filter stage has a double inversion, the polarity of the signal is correct as shown. It should be noted that the positive

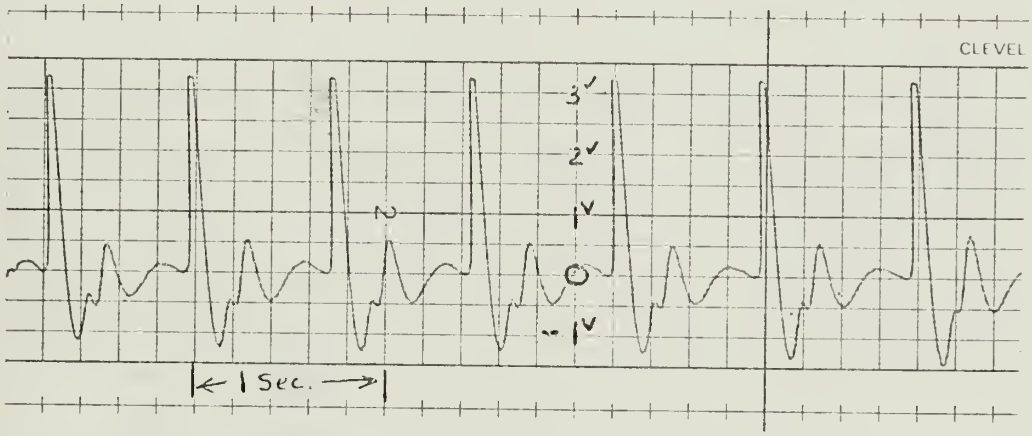

Figure 4. Gain/Filter Stage output human subject, gain = 20.

excursion of the signal represents the actual "beat" of the heart, and its magnitude is proportional to the change in aortic pressure during the "beat." The negative excursion of

the signal is not related to the heart function, but merely represents the face of the transducer relaxing to its equilibrium position.

A simple peak rectifier circuit was chosen as the best method of measuring the relative amplitude of the output pulse wave. Since this amplitude could vary widely depending on how tightly the transducer was affixed against the peripheral pulse pressure point, 12 volts peak was chosen as the maximum signal strength to be expected, and 6 volts peak as the standard, or reference output. It was decided that, in operation, the output strength would be initially adjusted to this value, with the transducer in place, and variations recorded as a percentage deviation from this original point. This method allowed for various size animals, eliminated a difficult procedure for attempting to attach the transducer with the same pressure each time, and allowed the use of a simple and inexpensive output device: a 0-50 microammeter.

Due to the low frequencies involved, the time constant (RC) of the peak envelope detector had to be quite long. This

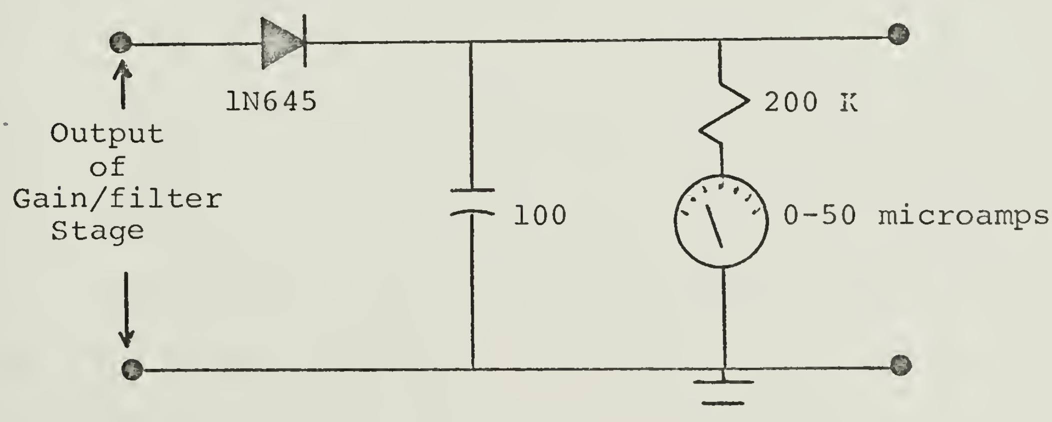

Figure 5. Pulse Strength Indicator.

implied a large resistance, since large capacitances get quite cumbersome. The resultant circuit, shown schematically in figure 5, uses a microammeter in series with this large resistance as an indication of pulse strength, because any reasonably priced voltmeter in parallel with it would lower the effective resistance so much that the circuit would not work properly. The component values were chosen so that the 6 volt peak reference output of the gain/filter stage would produce mid-scale deflection of the microammeter, and the meter scale was altered to read low-normal-high percentage vice microamps.

D. THE AUDIO/VISUAL HEARTBEAT INDICATOR

The requirement for this stage of the device was that it provide some form of audio and/or visual indication that the heart was or was not beating. Naturally, this stage would also give the operator some intuitive idea of the pulse rate. Since this was to be only a monitor function, it was decided that the "beep" of a simple audio oscillator would be much less expensive to reproduce than the actual heart sound, and would serve the purpose just as well.

A cathode ray tube trace presentation was considered initially as the visual indicator, but some discussion with practicing veterinarians revealed that they would not have time to closely observe the pulse wave pattern during surgery. In fact, the visual indicator was desired as an adjunct to the audio indicator; something that would still give a heartbeat

indication if the audio indicator became too bothersome. The obvious answer to this was a small light that would flash each time the heart beat.

The problem of how to turn the light and the oscillator on and off once for each heartbeat at low power levels was admirable solved by the use of a Silicon Controlled Switch in the latching mode. In this configuration, the SCS is switched on by a positive pulse and off by a negative pulse. Fortunately, the heart pulse signal already contained one of each for each heartbeat (see figure 4).

The audio oscillator circuit chosen is a common one, often used as a Morse Code practice oscillator. It was chosen because it requires few components, is small in size, requires no transformer or separate output stage, and is therefore inexpensive. Since the oscillator itself is above ground, it also permits including the indicator light in this portion of the circuit, eliminating the need for another SCS.

A schematic representation of the Audio/Visual heartbeat indicator stage of the VETSMON device is shown in figure 6. Note that the visual indicator can be switched in or out of the circuit, and that the 50 ohm potentiometer in parallel with the speaker acts as a volume control.

The 1.5 K resistor in series with the gate of the SCS ensures that the load of the operational amplifier in the gain-filter stage is not shorted out when the SCS turns "on." The zener diode in parallel with the gate input is to drain off some of the current from any large or transient input pulse

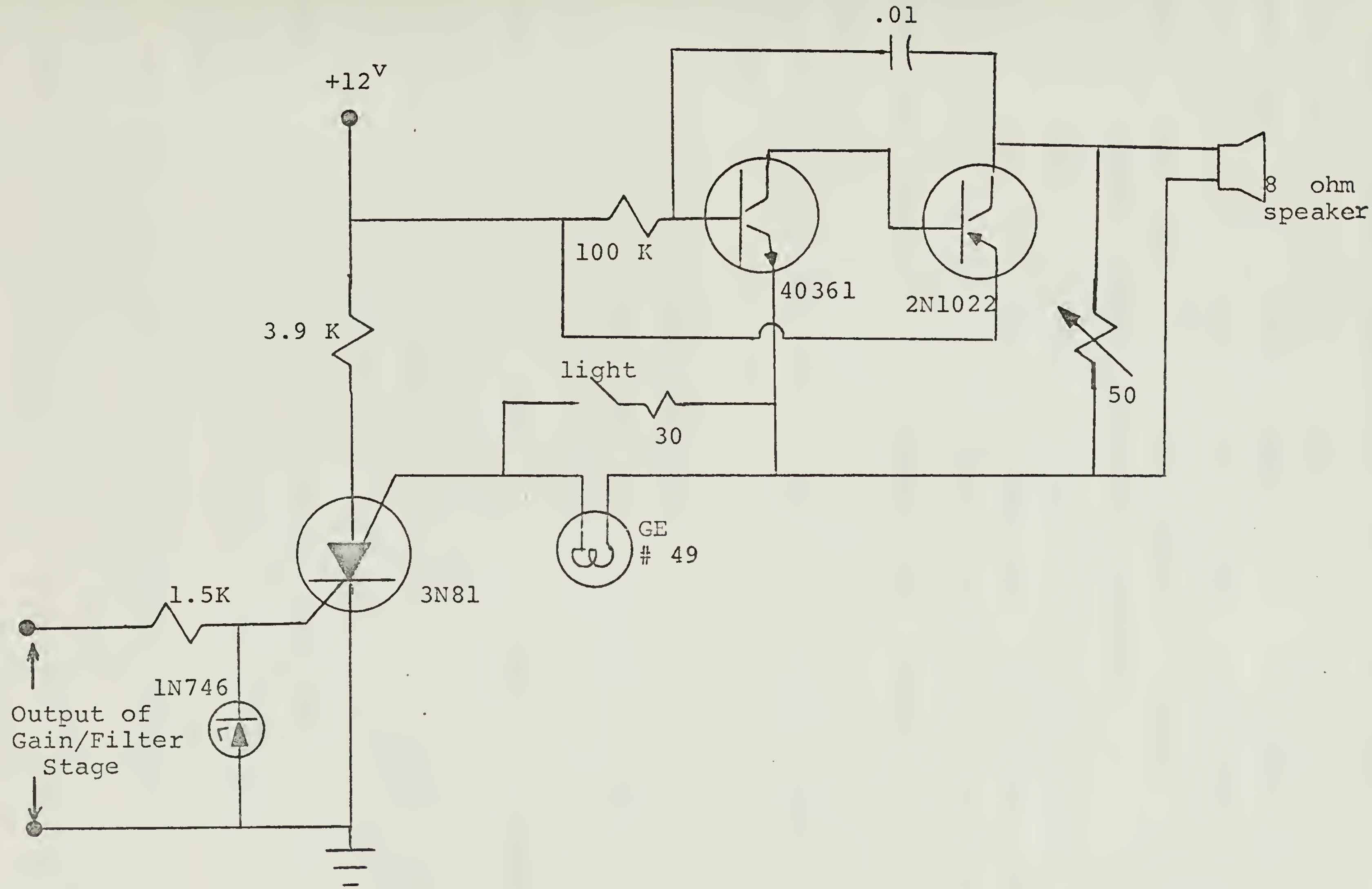

Figure 6. Audio/Visual Heartbeat Indicator.

in order to prevent excess current flow in the oscillator/ flashing light "load" of the SCS. Investigation of a bread-board model of this circuit showed that a very large signal at the cathode gate of the SCS was capable of increasing the current in the anode gate circuit enough to burn out the GE #49 bulb, which is only rated at 60 milliamps.

This circuit is the major current user in the VETSMON device, when it is in the "on" condition. It's current demand varies from near zero in the "off" condition to 80 milliamps in the "ON" condition, which implied that the plus 12 volt supply had to be well regulated. This subject is covered in more detail in the section on design of the power supply circuits.

E. THE PULSE RATE INDICATOR CIRCUIT

The desire to measure the pulse rate suggested many types of frequency measurement or counting circuits, such as binary chains or ring counters. These circuits, however, would have required a separate gate circuit and some form of stable oscillator in order to measure frequency, and a stable oscillator at the low frequencies desired would have been inconvenient. Also, this form of frequency measurement can be very accurate, but would have been expensive due to the circuitry involved.

The simple capacitive storage counter was considered as a solution to the problems of complexity and cost, and it was the basis for the final design. The two-diode storage counter

could not be used in its usual form because the amplitude of the input pulses was not constant. This would have required some correlation between the pulse strength indicator and the storage counter to produce a measurement of frequency. An additional problem was the low frequency of the pulse signal. This limitation would have meant that a considerable interval of five or six input pulses would have had to pass between each information output. At higher frequencies this would not have been an important problem, but at about one hertz it meant a delay of five to six seconds between outputs, meaning that some form of storage display device would have been required. Once again, expense was the limiting factor.

The final choice was a modification of the diode storage counter, with the circuit arranged to measure the interval between successive positive going pulses as a direct indication of pulse rate. A schematic representation of this circuit is given in figure 7.

When no pulse is applied to the gate of the silicon controlled rectifier, it is off, and capacitor C_1 is charging towards 24 volts through resistor R_1, with time constant R_1C_1. A positive pulse at the gate turns the SCR "on" and C_1 discharges through it very quickly. Therefore, the amplitude of the waveform associated with C_1 is a direct indication of how long the SCR was in the "off" condition, which is the time interval between pulses.

The remainder of the circuit is a peak envelope detector used to measure the voltage amplitude described above. The

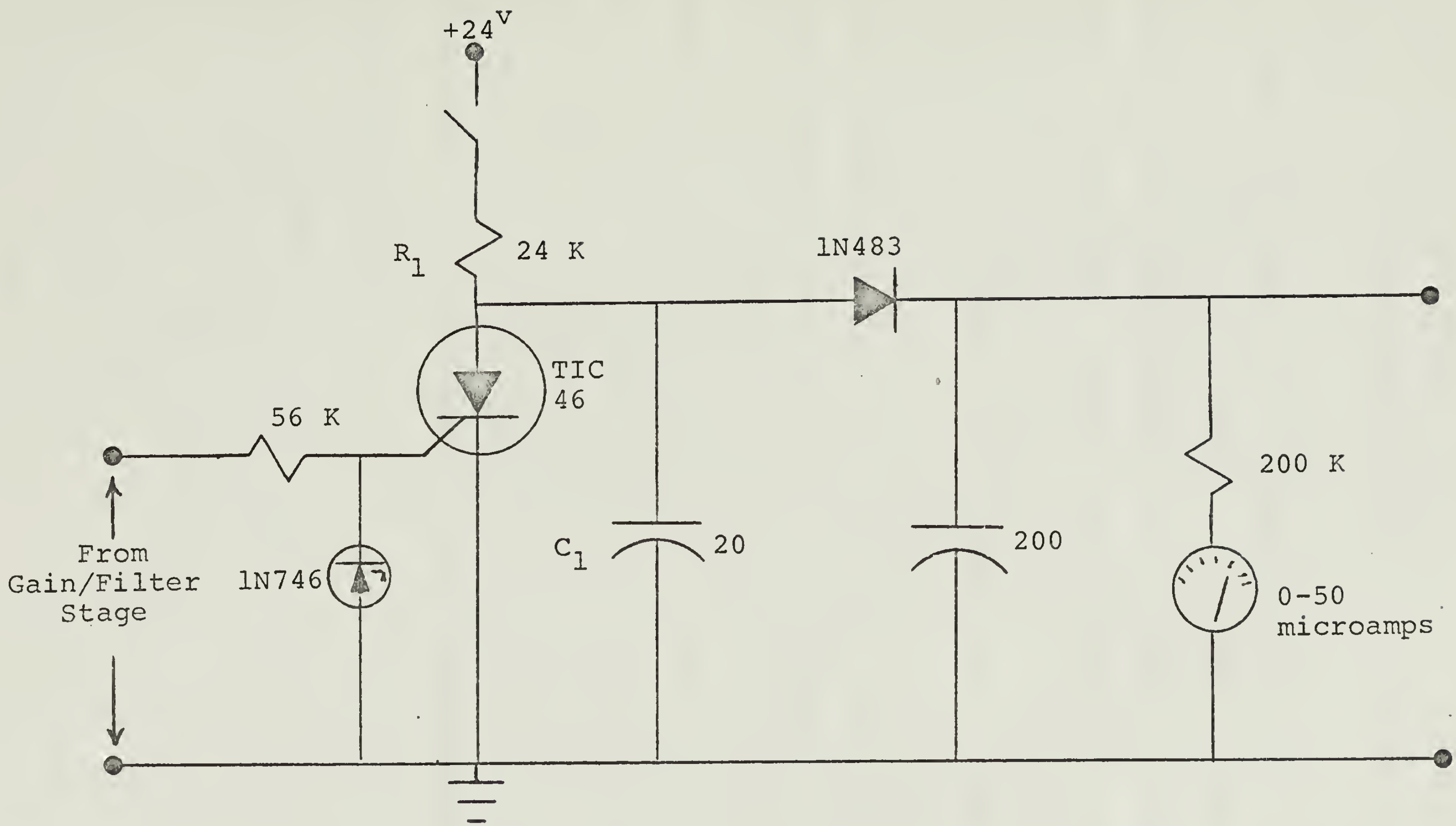

Figure 7. Pulse Rate Indicator Circuit.

indicating device is a 0-50 microammeter, which was chosen for the same reasons that apply to the pulse strength indicator circuit. In this case the meter was recalibrated in pulses per minute.

It should be noted that changing R_1 to a 50 k resistor would have permitted using this circuit with a human subject. The change would have been necessary to keep the output within the range of the meter, as the normal human heart rate is only about half that of a dog. Also, the large gate resistor was included as a current limiting resistor, so that a pulse of at least two volts peak is required to turn on the SCR. This was necessary because the peripheral pulse wave actually has two pulses for each heartbeat (see figure 4). There is a larger pulse which represents the systolic pressure pulse, followed by a smaller diastolic pulse as the heart chambers refill with blood. In some pulse waves the diastolic pulse may be as much as one fourth the size of the systolic pulse, which meant that, without the current limiting resistor there was the possibility of erroneous pulse rate measurement.

F. THE ALARM CIRCUITS

The requirement for alarm circuits seemed, at first, the most difficult requirement to fulfill. A total of four indications were required; high pulse pressure, low pulse pressure, and high and low pulse rate. The simplest solution to the problem seemed to be to replace the fifty microamp D.C. meters used in the pulse rate and pulse strength circuits with control meter relay devices of the dual set point type. Some

investigation revealed that while this was the simplest and most direct method of providing an alarm indication, it was also the most expensive. All meters of this type available commercially cost more than one hundred dollars each, even in moderate quantity lots. Since two meters would have been necessary, the cost was considered prohibitive. Another consideration was that most types of meter relays require a 117 volt A.C. power supply, which would have meant that the unit could not be field portable. A few D.C. power supply models are available on a special order basis from companies such as Beede Instruments, but these are even more expensive than the A.C. operated models.

Electro-mechanical relays, mercury, and dry reed relay switches were also considered, but found unsuitable. These types of devices do not operate at low enough voltage and current levels to have been useable in the device proposed, except for some contact relays which require an A.C. power supply. They also had the disadvantage of not being adjustable over a range of trip out or pull in voltages, and it was desired to give the operator some control over the points where the alarms would actuate.

The only remaining solution seemed to be some form of purely electronic switch, and preferably, one with which the switching level was variable. This desire for a variable switching level led to consideration of the unijunction transistor.

The unijunction transistor is useful in sensing circuits, such as the ones desired for alarm indicators, because its static emitter characteristic curve shows a negative resistance region. The switching voltage lies between a high positive resistance region and this negative resistance region, and is denoted by V_p, the peak point voltage. This peak point, or threshold voltage is determined by the bias voltage, the bias resistors, and N, the intrinsic stand-off ratio, from the following equation:

$$V_p = NV_{BB} + V_D \tag{1}$$

V_{BB} is the base one to base two voltage determined by the bias voltage and the bias resistors, and V_D is the voltage drop across the emitter diode with a forward current equal to the peak point current (essentially a constant). Since N is a measureable constant of the device, there is a linear relationship between V_p, the emitter voltage which will cause the device to switch to the on condition, and the bias voltage which is applied to the device.

It was this characteristic of the unijunction transistor which formed the basis for the design of the alarm circuits shown in figures eight and nine; the former being a low voltage indicator and the latter a high voltage indicator.

Since the UJT itself could not switch enough current to operate an alarm light in series with it, it was utilized as the trigger device for an SCR similar to the one used in the pulse rate indicating circuit. This was also necessary

because it was desired to make V_{BB} variable in order to have an adjustable set point, meaning that the voltage available to a lamp in series would have also been variable, causing the indicator lamp to either burn out or not light at all, depending on the alarm level setting. The 2N4891 UJT was chosen because of its high intrinsic stand off ratio (approx. 0.83), and the TIC 47 SCR was used because it is small, inexpensive and conservatively rated to carry one hundred milliamps D.C. current.

Figure 8 is a schematic of the basic circuit used as a high voltage indicator, which corresponds to the high pulse pressure alarm and the low pulse rate alarm. V_{in} is taken as the output of the peak amplitude detector in each of these two circuits, and V_{BB} is determined by the setting of the one kilohm potentiometer. The UJT switches "on" when V_{in} exceeds 0.83 times V_{BB}, thus turning on the SCR and the GE 49 lamp.

Figure 9 represents a slight modification of this circuit, which is used as a low voltage indicator, corresponding to the low pulse pressure alarm and the high pulse rate alarm. This circuit works in much the same manner as the low voltage indicator, except that the roles of V_{in} and V_{BB} are reversed; the circuit switches "on" when V_{in} drops to a value which is 1.25 times the voltage on the arm of the one kilohm potentiometer. The ganged switch shown in each of these circuits is a double SPST switch with opposing contacts. In the RESET position, it removes voltage from the indicator light, and turns off the UJT.

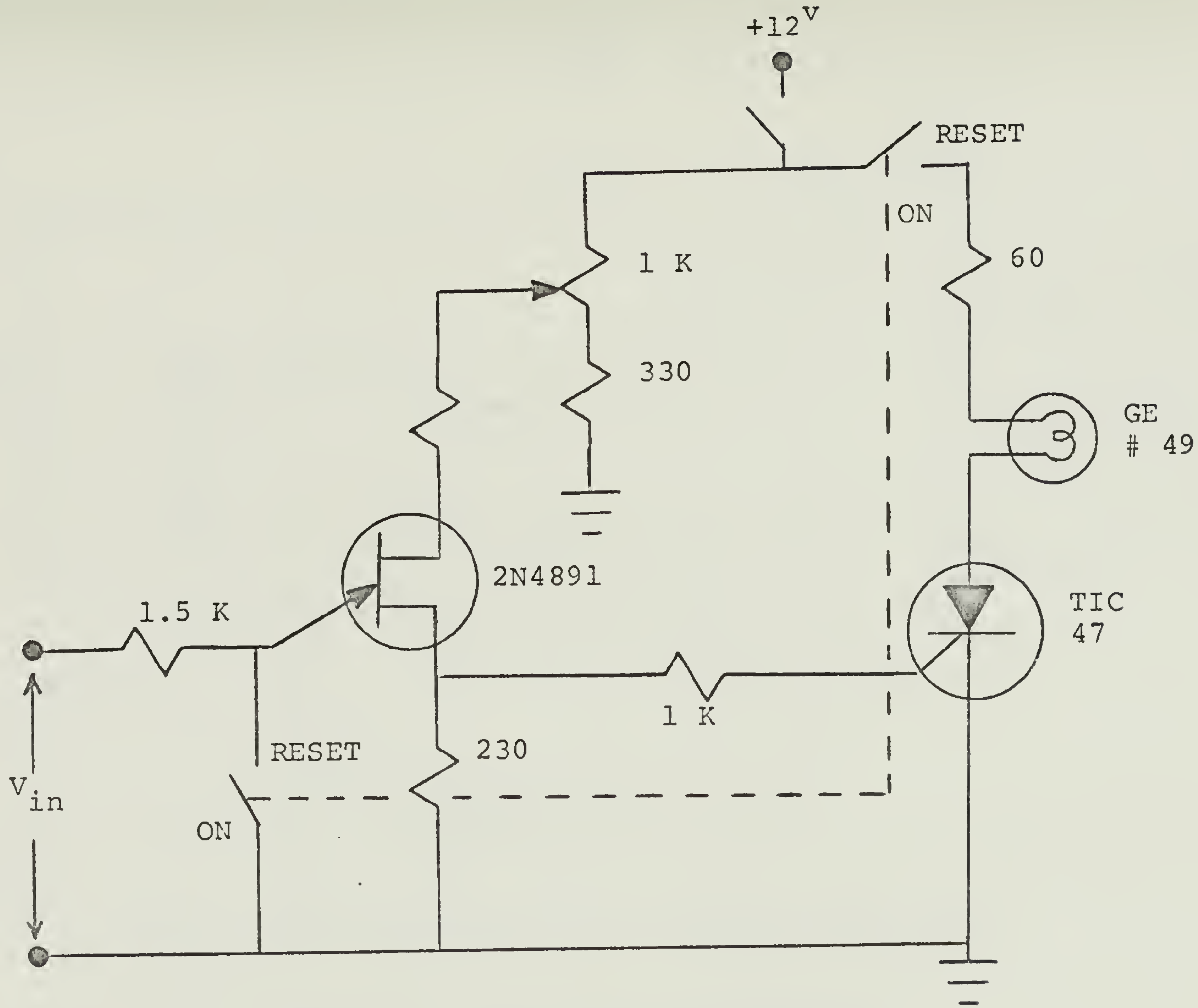

Figure 8. High Voltage Indicator.

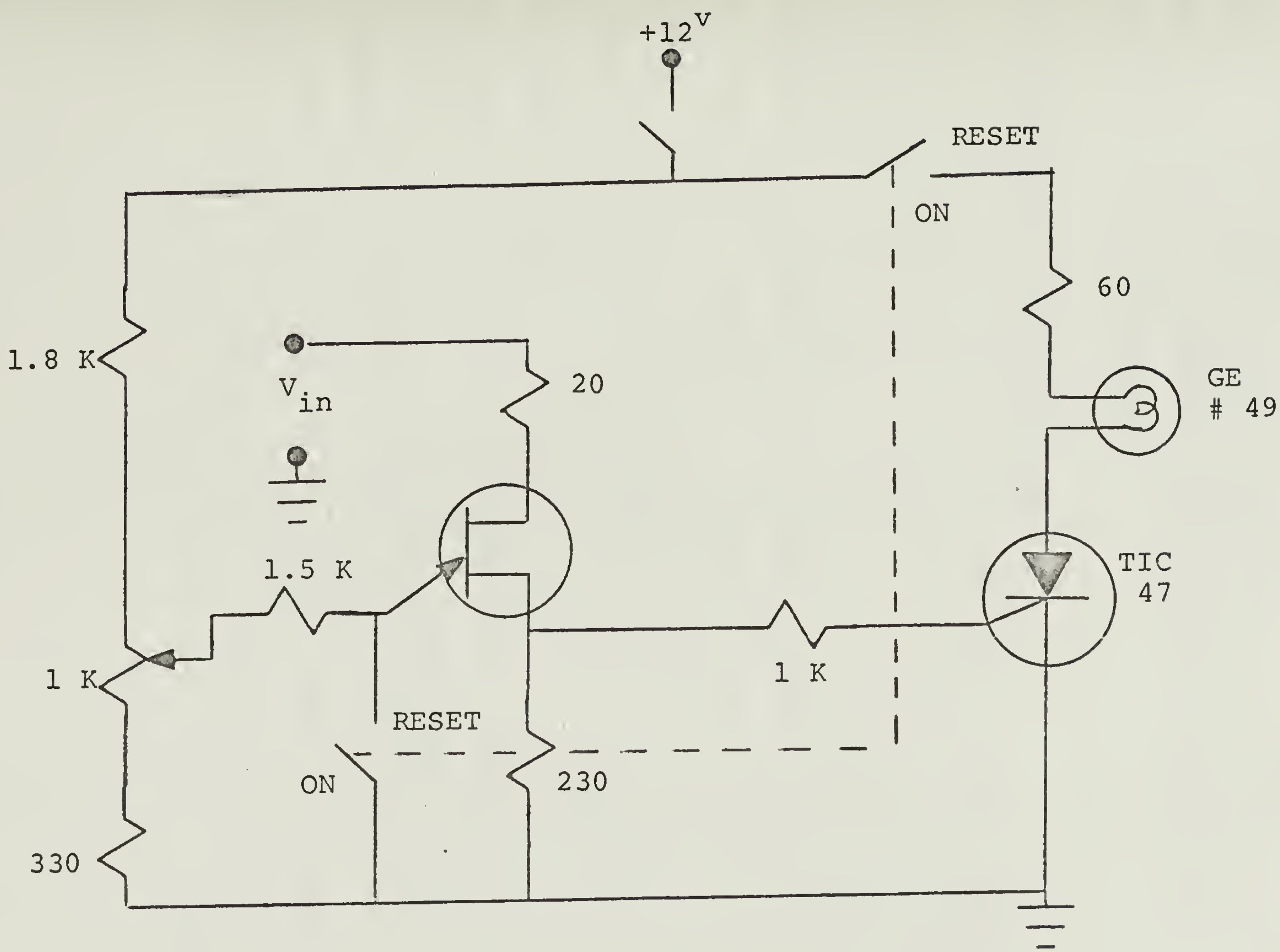

Figure 9. Low Voltage Indicator.

In order to provide an audio indication that one of the alarm circuits had been actuated, it was decided to place a simple D.C. operated buzzer in series with the parallel combination of SCR's, so that the activation of any alarm circuit would energize the buzzer. The new MALLORY "SONALERT" was found to be ideal for this purpose. As is shown in figure 10, the buzzer can be switched out of the circuit at the discretion of the operator.

G. PERIPHERAL OUTPUT DEVICES

In order to satisfy the desire for a visual representation of the pulse wave, inclusion of a cathode ray tube display was considered. This idea, and the idea of a strip chart recorder output as a permanent record were dropped from the basic plan for the device, however, because it became obvious that neither device is cost effective. Both would have added considerably to the cost of the device, and neither would have provided the operator with any additional information. An oscilloscope display of the pulse wave, although aesthetically pleasing, would have provided only the amplitude and frequency information already produced by the pulse strength and pulse rate meters, and would have required some interpretation even to get that. The same is true of the strip chart recorder.

As a compromise, it was decided to include an auxiliary output terminal on the panel of the device, where a sampling of the output of the gain/filter stage could be obtained. Thus, the initial cost of the device was kept down without

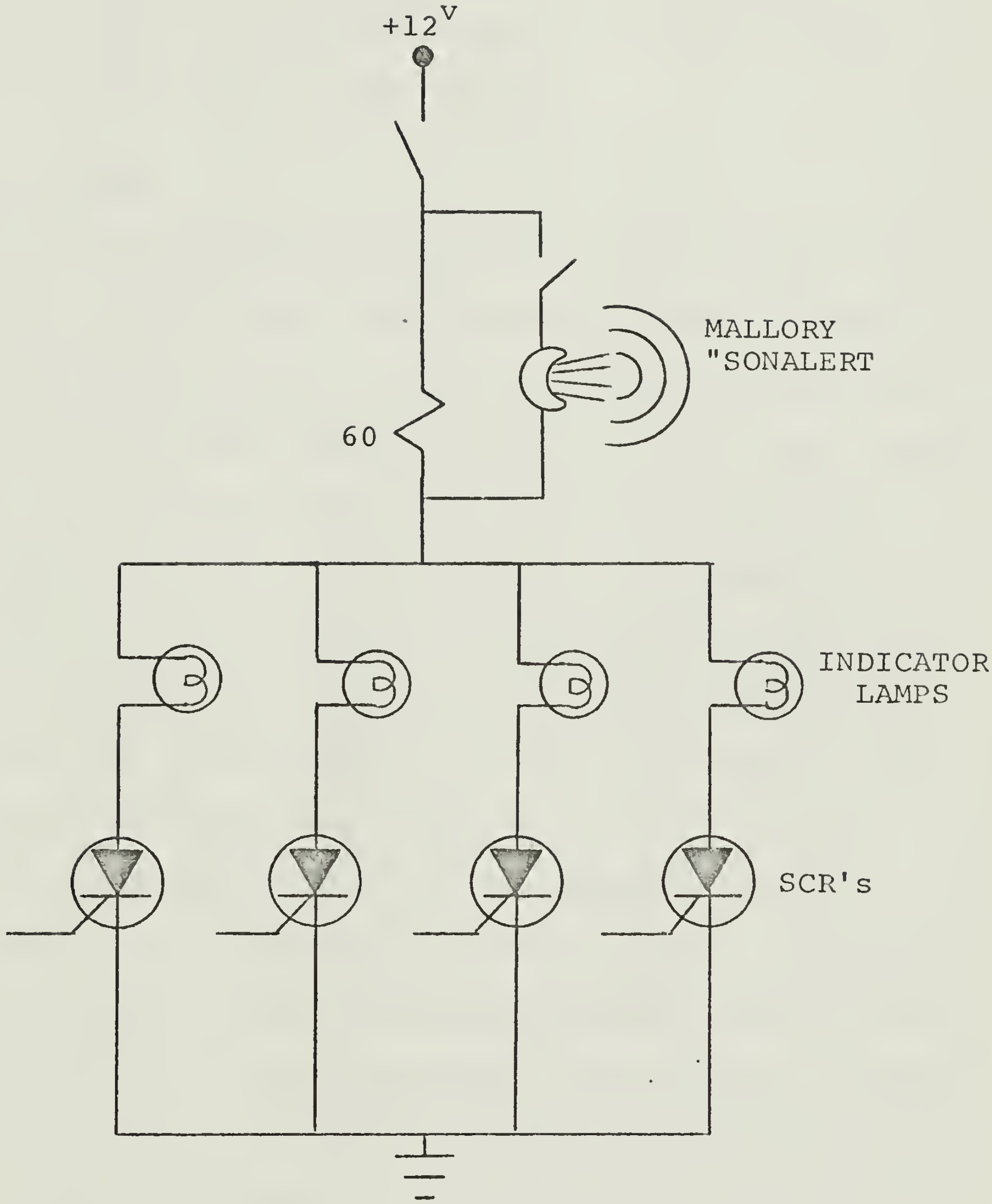

Figure 10. Audio Alarm Connection.

losing the possibility of having a visual pulse wave indication. If the device were ever produced commercially, a small oscilloscope and/or a strip-chart recorder could be made available as auxiliaries, at extra cost.

H. POWER SUPPLIES

A review of the circuits discussed so far indicated that three sources of D.C. power were necessary. Every effort was made to keep these sources as simple and compact as possible. The positive twelve volt supply required the best load regulation, while the negative twelve volt and positive 24 volt supplies feed essentially constant loads. Fortunately, extremely tight line regulation of the positive twelve volt supply was not necessary, and since the current demand was variable, but low, it was possible to use the simplest form of transistor emitter-follower regulator in this circuit. Since the negative twelve volt and the positive 24 volt supplies were to feed essentially constant loads, it was possible to use the even simpler and less expensive form of zener diode regulation. A single transformer with multiple secondary windings would have been preferable from a cost/weight standpoint, but it was not possible to locate one with the correct windings, except for those with a multi-tapped secondary. This type of transformer was not suitable for use where both a positive and negative ground are required.

Except when one of the alarm circuits was activated, these circuits would provide power in the following proportions:

$$\left.\begin{array}{l}+12\text{ volts @ 18 ma.}\\ +12\text{ volts @ 85 ma.}\end{array}\right\}\text{ 50\% duty cycle}$$

-12 volts @ 4 ma.

+24 volts @ 1.2 ma.

thus constituting a peak power consumption of 1.1 watts, and an average power consumption of 0.667 watts. Activation of an alarm circuit would cause an increase in peak power consumption of 0.72 watts. Thus, for any operating condition, the average power consumption of the device was to be less than one and one half watts.

The power supply schematic design is shown in figure 11.

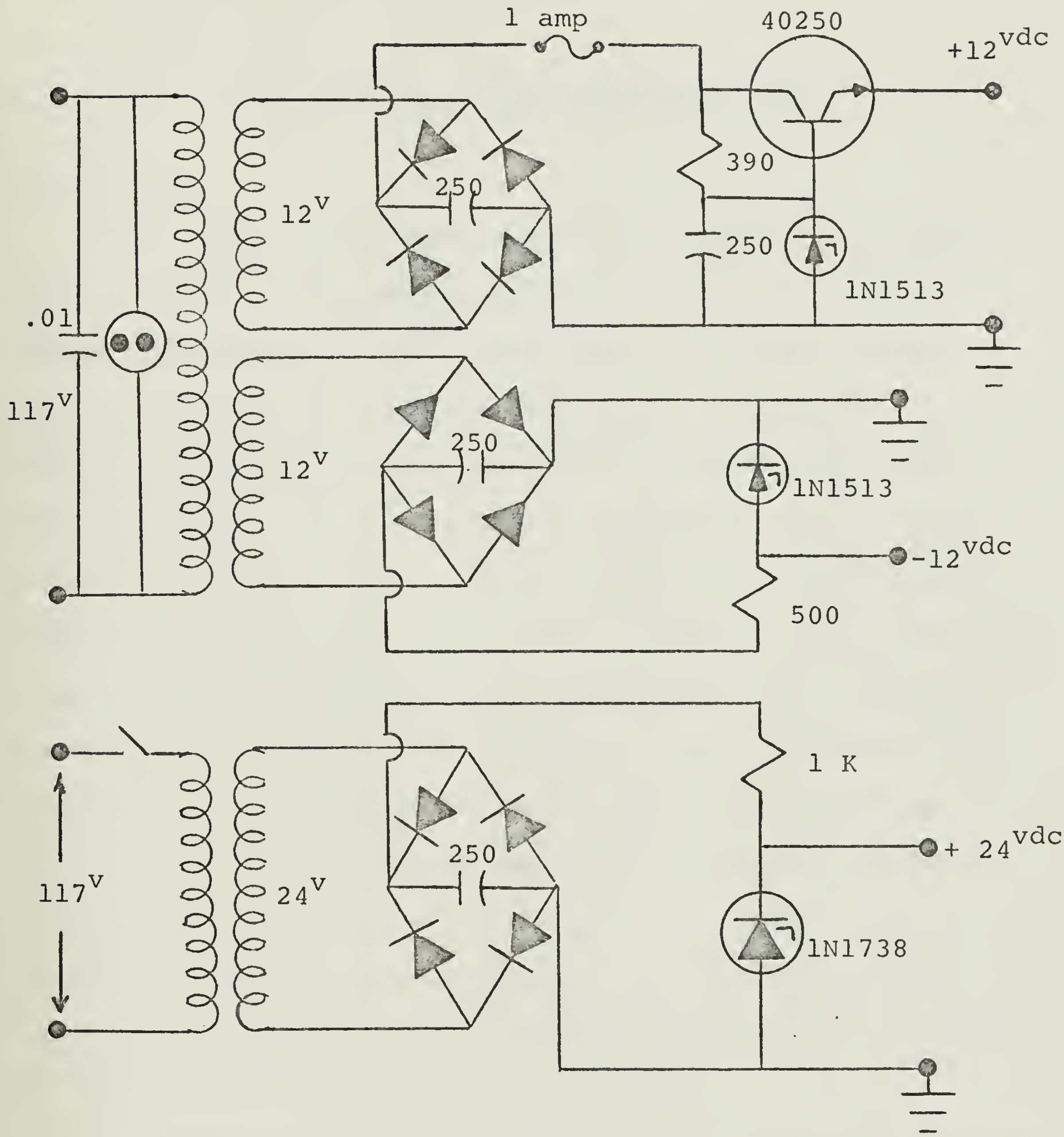

Figure 11. Power Supply Circuits (all rectifiers 1N647's).

III. INITIAL TESTS AND MOFICIATIONS

A. TESTING

Each stage of the device was constructed on a separate vector board, using spring clip connectors, in order to facilitate testing. All stages were tested for proper operation separately in the laboratory, using both a sine wave input and the input from the pulse transducer attached to a human subject. In addition, the gain/filter stage, pulse strength indicator, pulse rate indicator and audio/visual indicator stages were integrated and moved to the Marina Pet Hospital for field testing on animal subjects. Tests were conducted on animals under sedation, and all proved highly satisfactory. The animals used ranged from a five pound male cat to a 110 pound hunting dog, and the pulse transducer signals obtained from all were well within the range of the device. Specific recommendations for placing the pulse transducer and operation of the instrument are given in Appendix B of this thesis.

On completion of field testing, all stages were returned to the laboratory and the remaining stages integrated into the instrument for further testing, including the power supply stage. This final testing indicated the need for some modifications and additions.

B. MODIFICATIONS

(a) A 100 kilohm resistor was placed in series with the one megohm potentiometer feedback element of the RM741 operational amplifier to ensure that the feedback path would not be shorted by reducing the gain setting too low.

(b) Fixed resistors of appropriate values were placed in series with the one kilohm potentiometer in each of the alarm circuits, in order to spread the alarm settings for each alarm over the full range of the single turn potentiometer, and make these settings easier to control.

(c) It was found that an impedance matching problem existed between the pulse rate and pulse strength circuits and their various alarm circuits. Turn on of an alarm circuit effectively short-circuited the parallel R-C combination in the peak detector portions of the pulse rate and pulse strength circuits. This problem was solved by placing a buffer stage

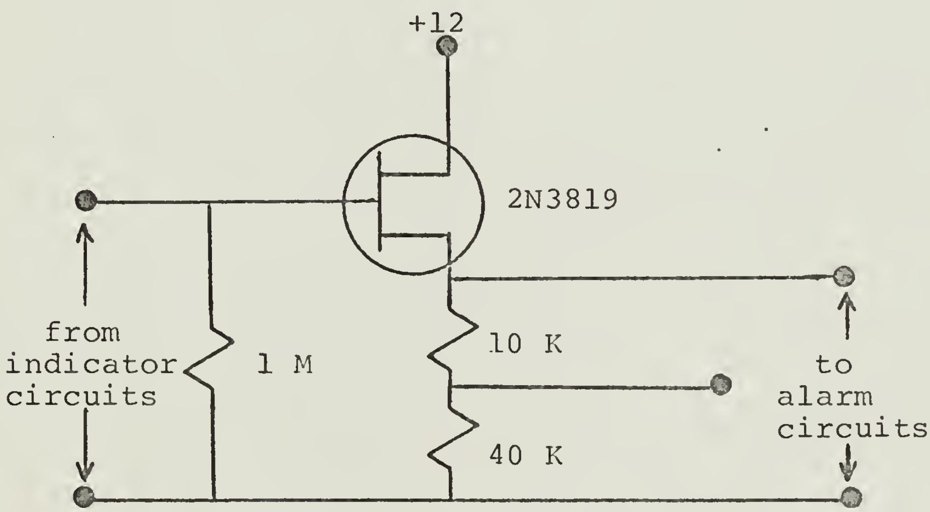

Figure 12. Alarm Circuit Buffer Stage.

at the output of each of the indicator circuits and using the outputs of these two buffer stages as inputs for the alarm circuits. FET's were chosen for these buffer stages because of their extremely high input impedance and good voltage follower characteristics. A schematic representation of the simple source follower buffer stages used is shown in figure 12. The emitter resistor is tapped down for the output to keep input and output D.C. levels compatible.

IV. THE PROTOTYPE MODEL

A. CONSTRUCTION

The final step towards realization of the VETSMON was fabrication of a working prototype of the device. It was intended that this model of the device be suitable for field testing and evaluation. The best approach from an esthetic standpoint would have been to have reduced the circuitry to plug in type printed circuit boards, but it was felt that since all construction was to be done by the author, this would have required time not justified by the end results. Also, due to funding limitations, it was necessary to use all of the peripheral components (switches, potentiometers, etcetera) which were already available, and the size of many of these components would have negated any beneficial size and weight decreases obtained from using printed circuit boards. Consequently, the basic circuitry was laid out in finished form on three sections of vector board. The power supply circuits, except for the transformers, were constructed on a standard four inch by eight inch piece of vector board, while all the alarm circuits were placed on a separate but similar board. All the remaining circuits were placed on a third piece of vector board, which measured four inches by ten inches. The only circuit components omitted on these boards were those which had to be accessible (meters, potentiometers, switches). These were placed on the VETSMON control panel.

The chassis and cabinet construction was limited by the type of material available, the facilities of the student shop, and the author's rather meager knowledge of metalworking techniques. Due largely to the latter limitation, the cabinet turned out to be quite a bit larger than was necessary, measuring twelve by fifteen inches at the base, and being fourteen and one half inches in height overall. It is felt that, if printed circuit boards and miniature switches were used, and some industrial know how applied to the cabinet design, the device could easily be made one half the size of the prototype.

The upper portion of the instrument panel of the device was sloped back at a 45 degree angle to permit easier viewing of the meters and alarm circuit indicators, while the basic control and switching group was mounted on the vertical bottom portion of the panel. All portions of the chassis and cabinet were constructed from 0.040 inch sheet aluminum, and the front panel was hand rubbed with emery paper and crocus cloth, in order to present a more uniform appearance.

Appendix A presents photographs of the final prototype version of VETSMON, but only exterior views were possible. Due to the large number of components mounted on the front panel of the device, there was enough internal wiring between the chassis and the back of the control panel to preclude meaningful photographs of the circuit boards. However, figure 13 is a chassis layout drawing, showing the location of each of the circuits described and drawn in the previous two chapters.

B. TESTING

The VETSMON prototype was bench tested using signal generator inputs and the input from a human subject, and found to be operating as designed. The device was then taken to the offices of the Monterey Bay Pet Hospital and field tested by the author and Dale C. Johnson, D.V.M. On completion of this field test, the device was left with Doctor Johnson over a period of three weeks for further evaluation. Periodic conferences between the author and Doctor Johnson, during this three week period, helped to define problem areas, obtain a realistic evaluation of the usefulness of VETSMON, and generate a set of recommended operating instructions and guidelines for users of the device.

The results of the testing and evaluation period are discussed in the following section, while Appendix B is composed of the operating instructions and user guidelines.

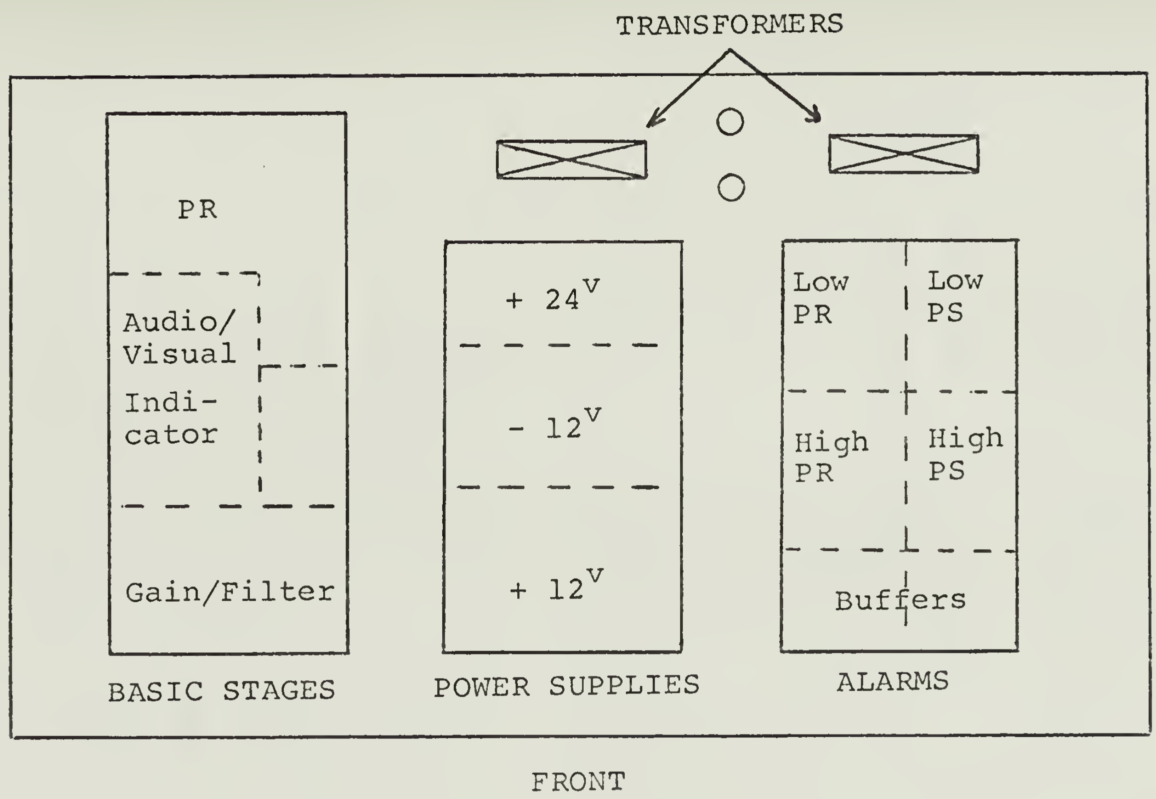

Figure 13. Chassis Layout (top view).

V. CONCLUSIONS

The initial three week testing period showed that the prototype model of VETSMON operates as intended, and is of considerable assistance to the veterinarian. This is not to say that the overall system is as efficient as it might be. The VETSMON instrument itself performs very well electrically, and reliably produces sufficient information for the operator to continuously monitor an animals overall condition. It is hoped that further testing and field use will result in an accumulation of data sufficient to evaluate and tabulate the clinical significance of the many possible combinations of pulse rate and pulse strength abnormalities that may arise during surgery.

The major shortcoming of the VETSMON system is the input device. All the considerations of section one of the Design chapter of this thesis were upheld throughout the research conducted, and the Harvard Model 361 Pulse Transducer is still considered to be the best choice from among the input devices that were available, but it is quite inconvenient to use on a fur-bearing animal. It is intended that future investigations be made into the use of the esophagial stethoscope/ pulse transducer combination, and into the possibility of using EKG information obtained from a wired hypodermic needle or towel clamp. EKG signals do contain less information of

immediate time use than the peripheral pulse wave, but convenience of use could become an over-riding factor.

The total cost for materials used in construction of the prototype model of VETSMON, including cabinetry and the pulse transducer is just under two hundred dollars. This estimate is based on retail price lists for the components used, and it is felt that with mass production techniques and quantity buying of parts, the unit could be commercially produced profitably at a cost to the customer of about two hundred and fifty dollars. Thus, the objective of producing a useful instrument at a cost of less than five hundred dollars has been well met.

In addition to the above considerations, it is felt that a slightly modified version of VETSMON would be of great use in the intensive care wards of human hospitals, since its low price would allow a hospital to have a unit for every bed in the ward, and permit one attendant to monitor a large number of patients. The device also may be used in monitoring human or animal subjects during medical research and experimentation.

VETSMON provides an important first step toward filling the technology gap in veterinary medicine, but this subject remains a wide open field for further research.

APPENDIX A

PHOTOGRAPHS OF PROTOTYPE EQUIPMENT

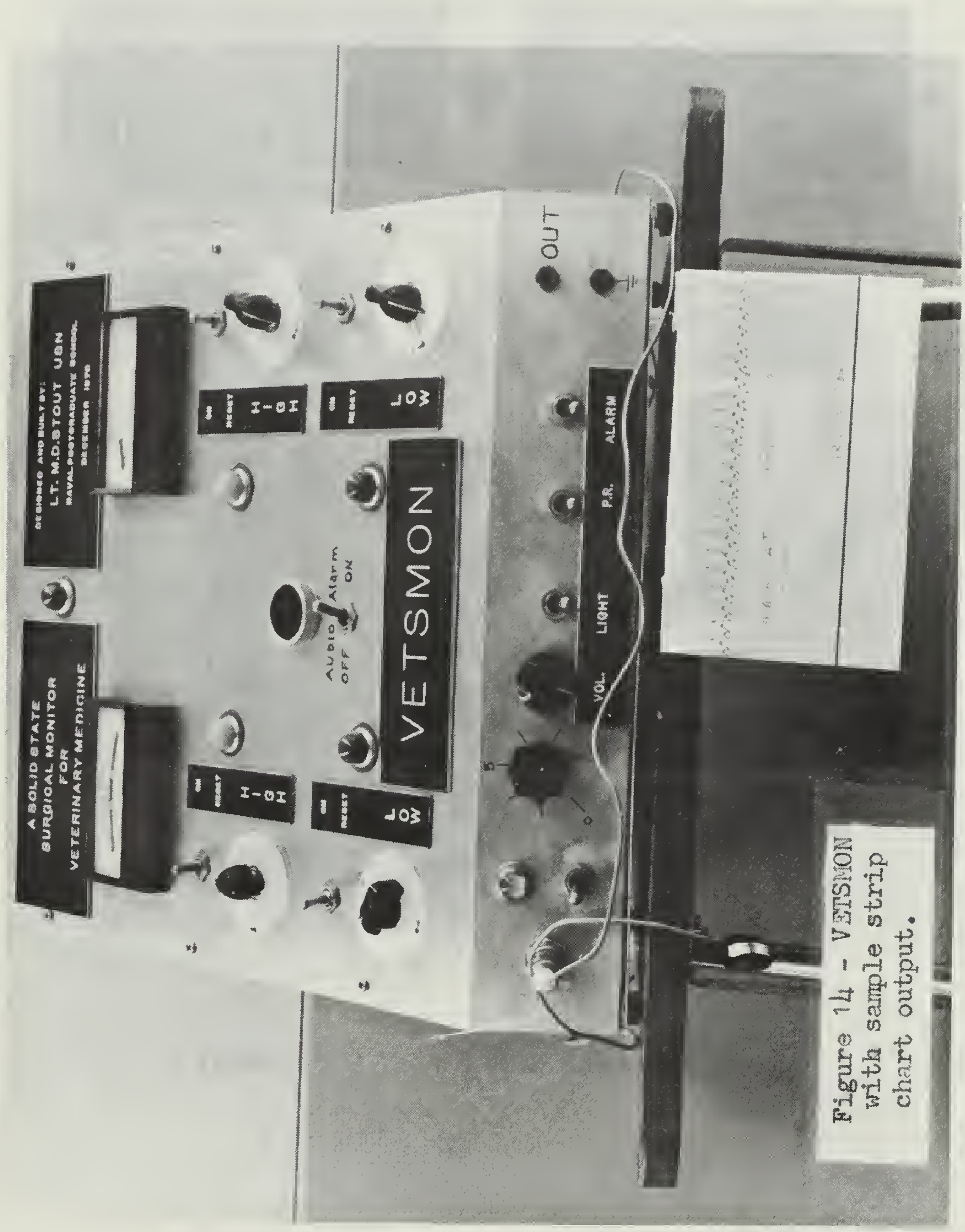

Figure 14 - VETSMON with sample strip chart output.

Figure 15 - The VETSMON indicator panel

APPENDIX B

VETSMON OPERATING INSTRUCTIONS AND USER GUIDE

CAUTION:

The Harvard Model 361 Pulse Transducer is a sensitive instrument. Irreparable damage will result unless the following cautions are observed!

A. Never expose the 361 to temperatures above 120°F.

B. Never expose the diaphragm to volatile solvents such as ether, carbon tetrachloride, etc.

C. Do not press the button of the diaphragm between the fingers. Too Much direct stress will fracture the transducing element!

Step-by-step operating procedure:

1. Before turning the unit on, place the transducer on the subject as follows:

The device may be placed anywhere on the subject that a good peripheral pulse can be detected. In order for any force to be detected and measured, it must have an opposing force against which it can act. Usually, this opposing force is supplied by taping the device on the subject. Johnson & Johnson "Elastikon" is excellent for this purpose. The transducer may be held against the body, but motion artifacts will usually obscure the signal. A rubber strap around the chest will suffice for acquisition of cardiac sounds. This

method is recommended for use with animals. It should be noted that the connecting cable should be immobilized by taping it to the body. This prevents any additional noise which might arise from cable motion.

To measure peripheral pulse on a human subject, tape the model 361 to the tip of any finger, with the tape taut enought to hold the transducer snugly against the tip of the finger.

Connect the transducer to the input of the VETSMON before turning on the power.

2. With the pulse transducer in place, turn the power switch "on." The light directly above this switch indicates when the device is on.

3. After approximately a 60 second warm-up period, some indication will be seen on the PULSE STRENGTH meter. Adjust the GAIN control so that the meter reads mid-scale. If mid-scale cannot be reached with the Gain Control fully clockwise, return to step one and tighten the strap on the transducer.

4. Adjust the VOLUME control for the desired level of output of the audio pulse signal. (Fully counter-clockwise is off.)

5. Turn the visual pulse indicator light "on" is desired.

6. Turn the PULSE RATE switch "on." (Do not turn this switch on unless there is some indication on the pulse strength meter.)

7. With all individual alarm switches in the RESET position, set the alarm level controls at the large dot on the scale for each control.

8. Turn the ALARMS switch to the "on" position, adjust the alarm level controls to the desired settings, and return all reset switches to the "on" position.

9. Activation of any alarm will cause the audio Sonalert to sound, and the alarm light associated with that condition to come on. The audio alarm only may be silenced by means of the switch mounted just below it. To remove the alarm light indication, and the audio alarm put the appropriate alarm switch in the reset position and either remove the cause of the alarm or increase or decrease the alarm level setting as appropriate prior to returning the switch to the "on" position.

10. A visual pulse wave indication may be observed by connecting any D.C. oscilloscope (or strip chart recorder) to the external output terminals, marked OUT.

SOME OF THE MORE IMPORTANT ARRHYTHMIAS IN DOGS

IRREGULARITY	OCCURRENCE/DIAGNOSIS
Sinus Arrhythmia --	Observed heart rate 65 to 120 ppm, rate increases on inspiration, decreases on expiration. No clinical significance.
Premature Contractions -	Occurs in myocarditis, myocardial degeneration, congestive heart failure, digitalis poisoning, and acute infections. Heart rate 100 to 150, sometimes at near normal. Heart beat occurs earlier than anticipated and the following diastole is prolonged. If proceeding diastole is short enough, second heart sound and peripheral pulse will be absent. Irregularity may disappear when rate accelerates. Ventricular extrastoles are most frequent in heart disease. Whether they occur in otherwise normal hearts is probable but not certain.
Atrial Fibrillation --	Occurs in congestive heart failure, especially in mitral or tricuspid insufficiency, and in digitalis toxicosis. Heart rate 190 to 250; rarely as low as 160. Absolutely irregular heart action

and weak pulse. Irregularity may increase when rate accelerates. This is a grave prognostic sign, usually only seen in the final stages of heart disease.

Atrial Flutter -- Occurs in same circumstances as Atrial Fibrillation, and in Quinidine treatment of that irregularity. Heart rate as high at 350 ppm. A definite diagnosis is impossible without an electrocardiagram. This is a grave prognostic sign, usually followed by Atrial Fibrillation.

Paroxysmal Tachycardia -- Occurs in congestive heart failure and myocardities. High heart rate, in some cases exceeding 360 ppm. Heart beats at a rapid, regular rate. Sudden onset and offset. May persist for weeks. This usually indicates a serious cardiac disease, such as myocardities, myocardial degeneration or metastatic neoplasms.

AV Block with dropped beats -- Occurs in degenerative or inflammatory myocardial lesions, as a result of certain drugs (e.g. digitalis, morphine), or when a high vagal tone is observed in the absence of heart disease. Heart rate 60 to 90 ppm, showing a slow, irregular rate. Artrial sound sometimes audible. This may or may not indicate heart disease.

Complete AV Block -- Occurs in severe myocardial disease and due to certain electrolyte disturbances. Heart rate below 50 and regular. Regular artrial sounds may be heard during ventricular diastole. Indicates severe myocardial disease, uremia or other severe electrolyte disturbance.

NOTE: A higher heart rate, around 160-180 ppm is normal in dogs under heavy sedation.

BIBLIOGRAPHY

1. Canine Medicine. Catcott edition. pp. 641. American Veterinary Publishers, Inc., 1968.

2. Fairchild Semiconductor Company. Linear Integrated Circuits Applications Handbook. Mountain View, California, 1967.

3. Fairchild Semiconductor Company. Second Generation Linear Integrated Circuits. Mountain View, California, 1968.

4. General Electric Company. G. E. Transistor Manual. Seventh edition, 1964.

5. Millman, Jacob and Halkias, C. Electronic Devices and Circuits. McGraw-Hill Book Company, 1967.

6. Millman, Jacob and Taub, H. Pulse, Digital and Switching Waveforms. McGraw-Hill Book Company, 1965.

7. American Radio Relay League. Radio Amateurs Handbook. 47th editon, 1970.

8. Radio Corporation of America. RCA Linear Integrated Circuit Fundamentals. New York, 1966.

9. Reference Data for Radio Engineers. Fifth edition. Howard W. Sams and Co., Inc., 1969.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Naval Ships System Command Navy Department Washington, D. C. 20360	1
4.	Professor Gerald D. Ewing Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
5.	LT Michael D. Stout, USN Nuclear Power School Naval Training Center Bainbridge, Maryland	1
6.	Dale C. Johnson, D.V.M. Bay Pet Hospital 2201 Fremont Avenue Monterey, California 93940	1
7.	Professor Sydney R. Parker Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
8.	CDR J. M. James, USN, Code 32, NPS, Monterey CA	1

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

A Solid State Surgical Monitor for Veterinary Medicine

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; December 1970

5. AUTHOR(S) (First name, middle initial, last name)

Michael Dinsmore Stout

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1970	55	9

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

A concept for an apparatus which provides audio and visual monitoring of the heart function is developed, including circuitry to give indications of abnormal conditions. The machine is intended for use during surgery by doctors of veterinary medicine, but also may have some application for monitoring of human patients. System design and principles applied to realize a physical prototype of this concept are presented. The complete electronic and mechanical design plus fabrication of the surgical monitor is described in detail. Schematic diagrams of all electronic circuitry employed and photographs of the prototype equipment are included, along with a set of operating instructions for non technically trained personnel. The device is on loan to the Monterey Bay Pet Hospital, Monterey, California, for further field testing and evaluation.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

Security Classification

A-31408

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Medicine						
Veterinary						
Surgical Monitor						

DD FORM 1 NOV 65 1473 (BACK)

S/N 0101-807-6821

A-31409

123477
Thesis
S783 Stout
c.1 A solid state surgical monitor for veterinary medicine.